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Takasan et al.

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(54) **VIBRATION ACTUATOR**

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(58) **Field of Classification Search** 310/323.01, 310/323.02, 323.04, 323.06, 323.13, 323.16, 310/323.17

See application file for complete search history.

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Primary Examiner—Thomas M Dougherty
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(57) **ABSTRACT**

It is an subject of the present invention to provide a vibration actuator in which a plurality of rotors can be driven by a single vibration unit.

When a composite vibrator (**2**) is driven to generate a composite vibration combining a plurality of vibrations, a first stator (**3**) and a second stator (**4**) vibrate, thereby causing elliptical movements in corner portions (**8**) and (**9**) of the first stator (**3**) and the second stator (**4**), respectively. As a result, a first rotor (A) abutting onto and pressurized against the corner portion (**8**) of the first stator (**3**) and a second rotor (B) abutting onto and pressurized against the corner portion (**9**) of the second stator (**4**) are rotated at the same time. Further, in this case, by selecting vibration modes of the plurality of vibrations constituting the composite vibration, the two rotors (A) and (B) can be rotated in the same direction or in opposite directions with respect to each other.

10 Claims, 15 Drawing Sheets

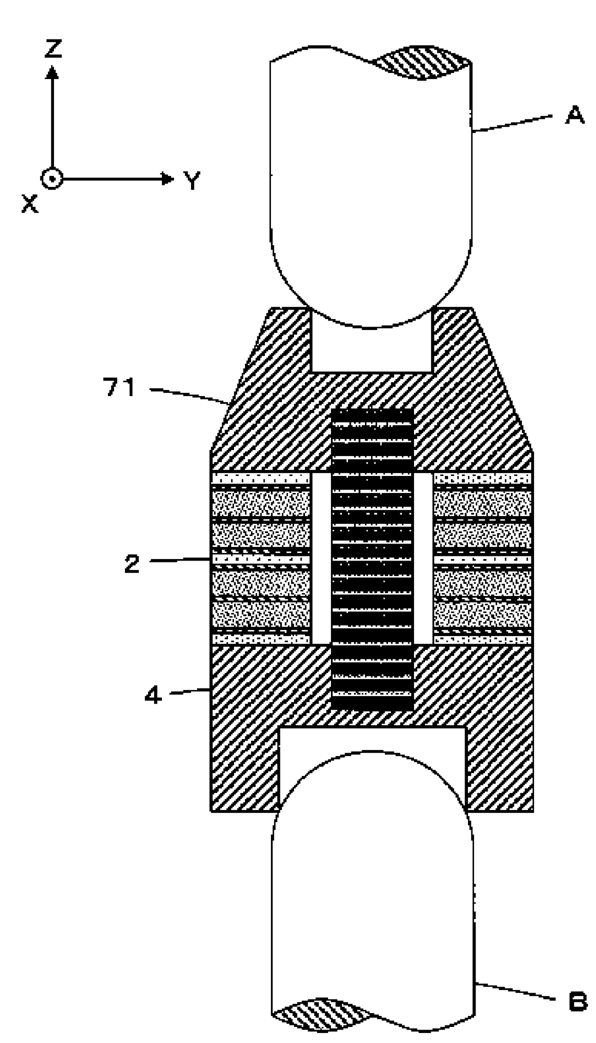

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FIG.1

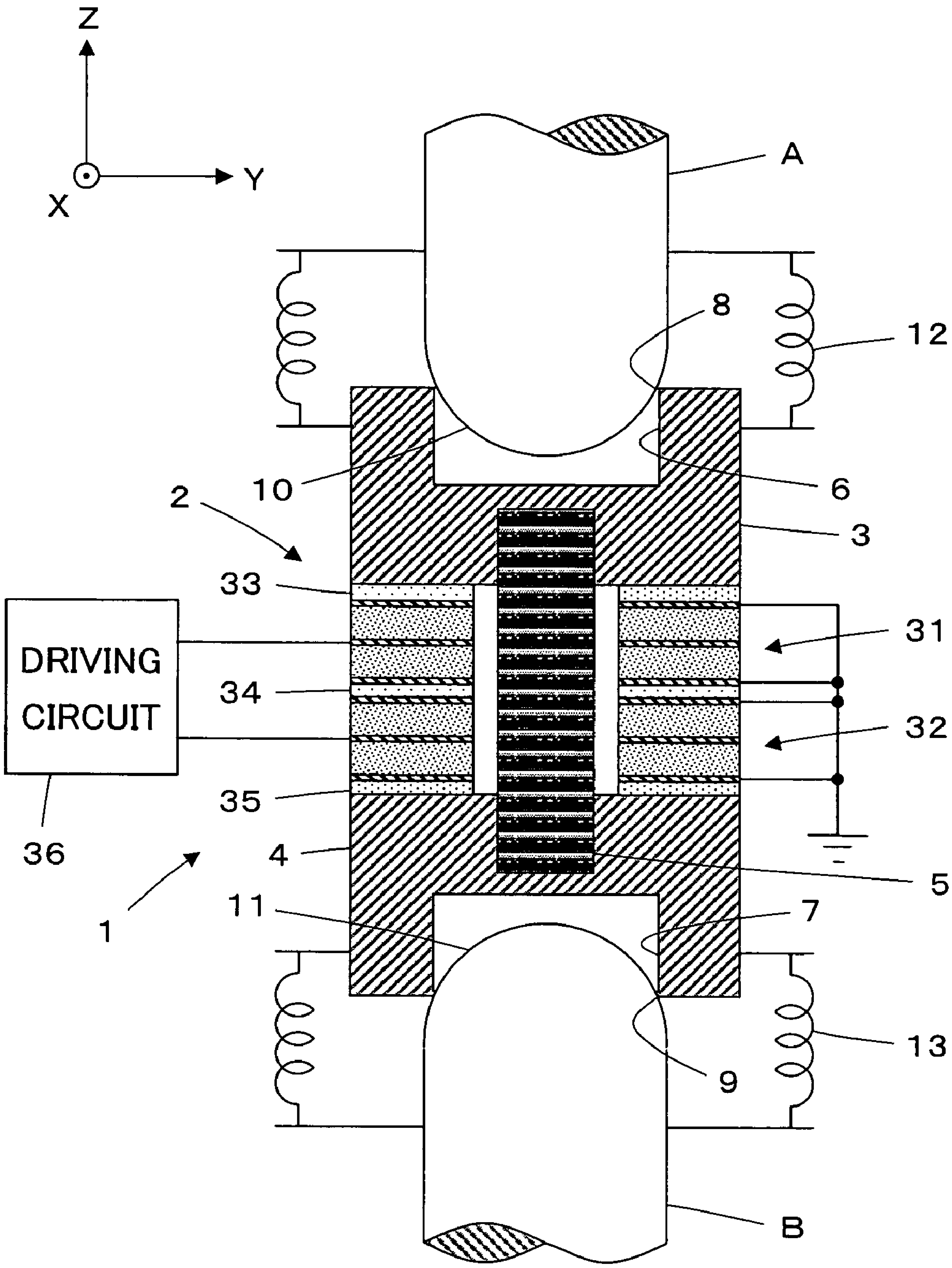


FIG.2

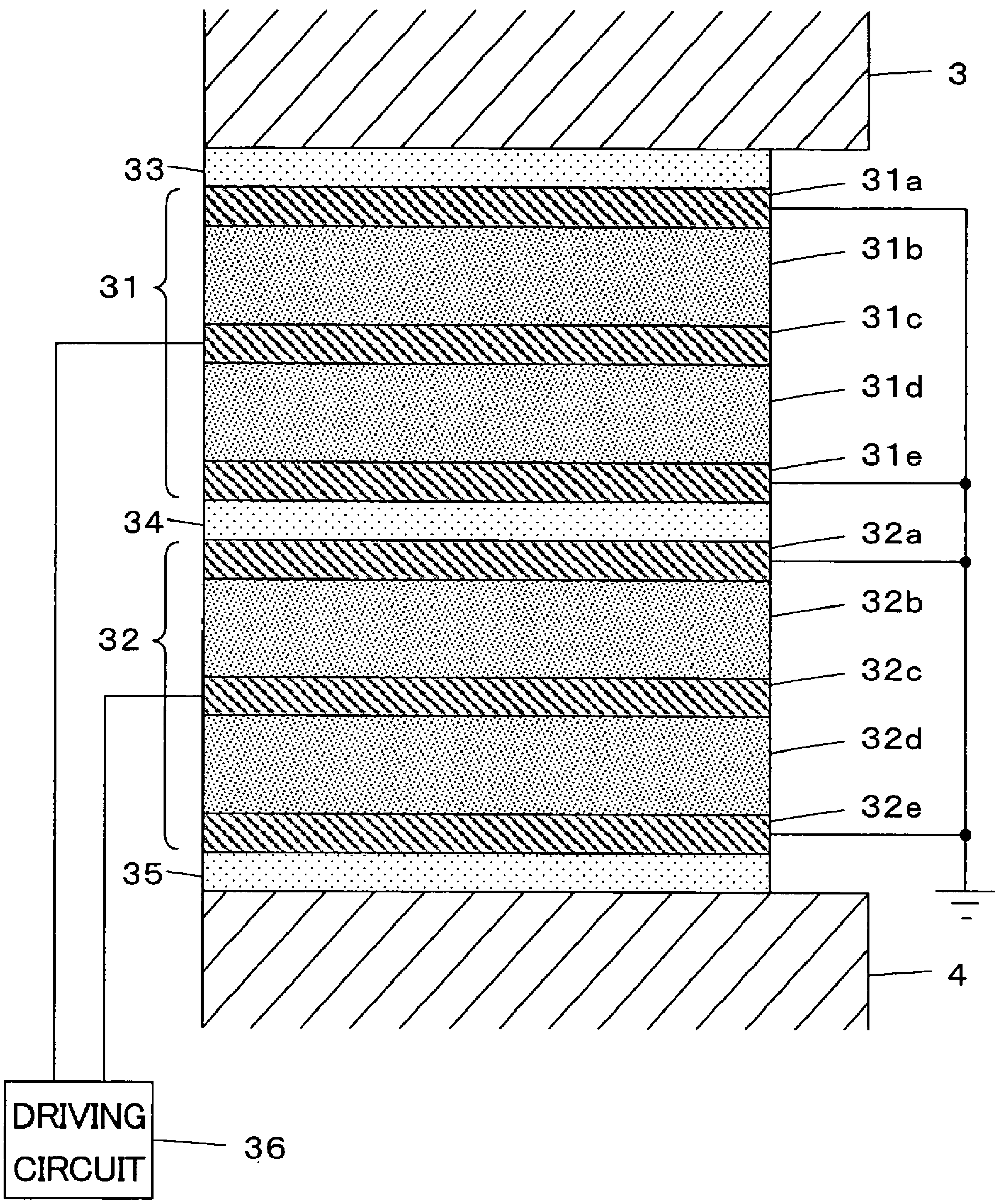

3
33
31a
31b
31
31c
31d
31e
34
32a
32b
32
32c
32d
32e
35
4
DRIVING CIRCUIT
36

FIG.3

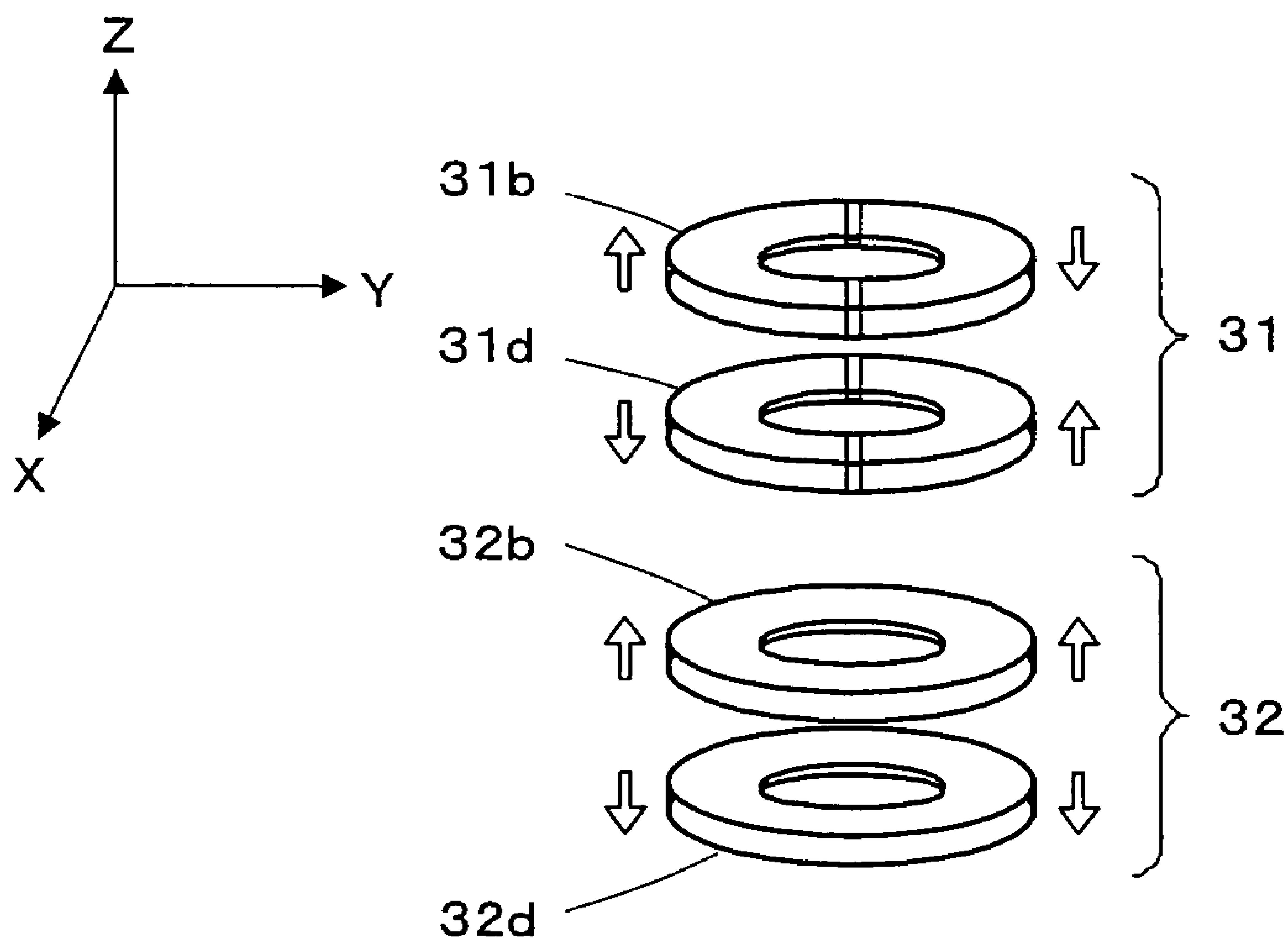


FIG.4a

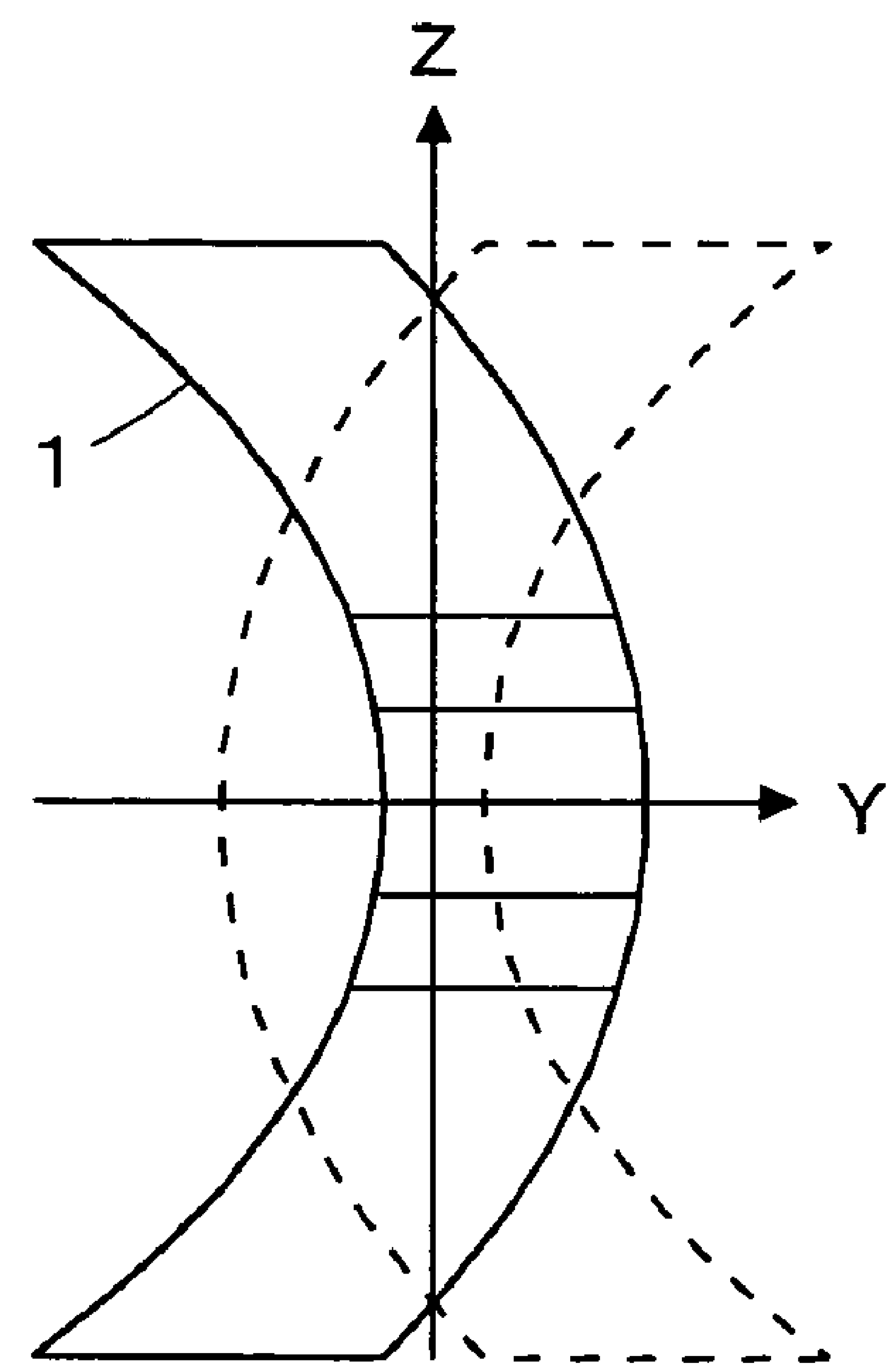


FIG.4b

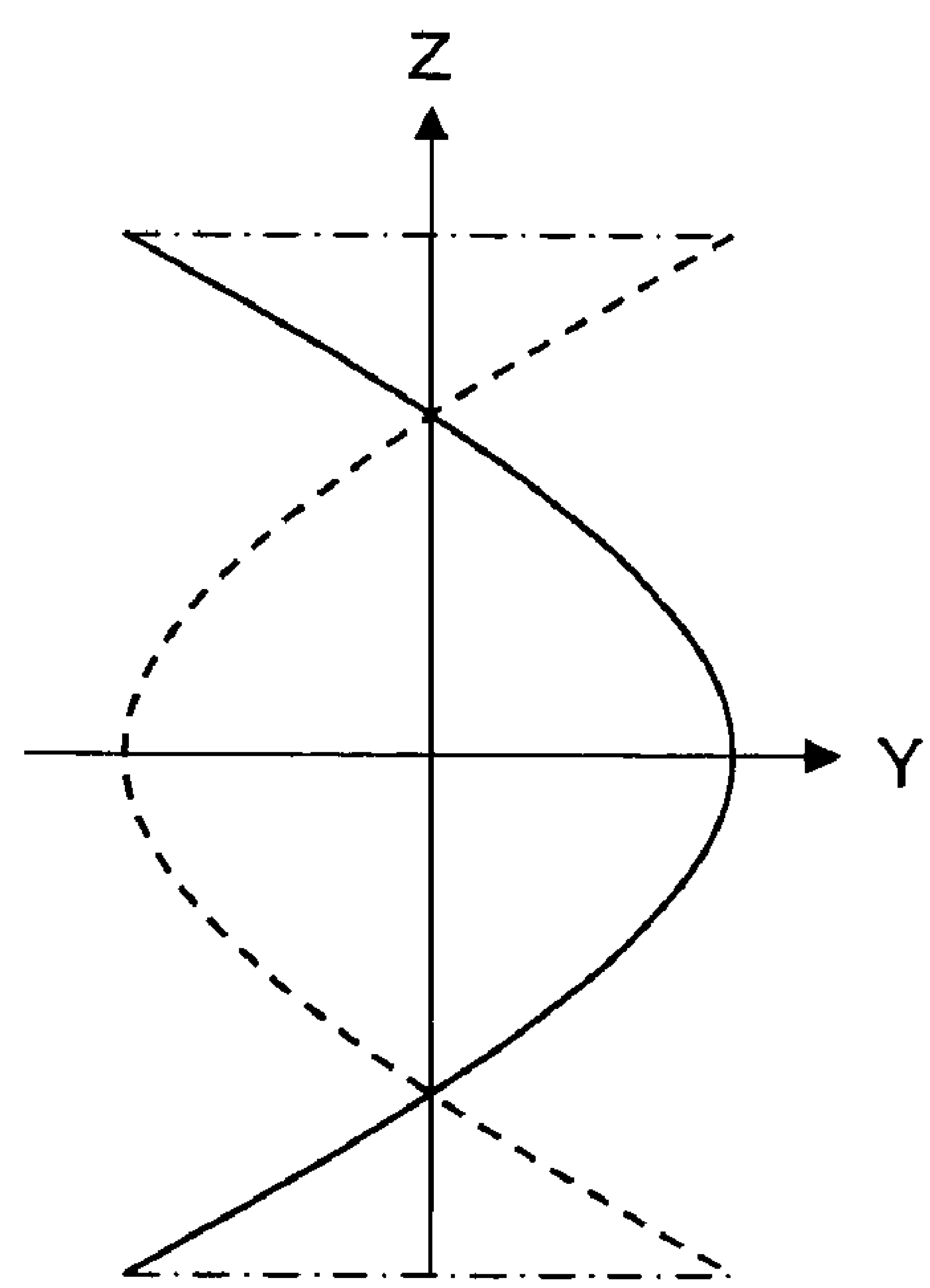


FIG.5a

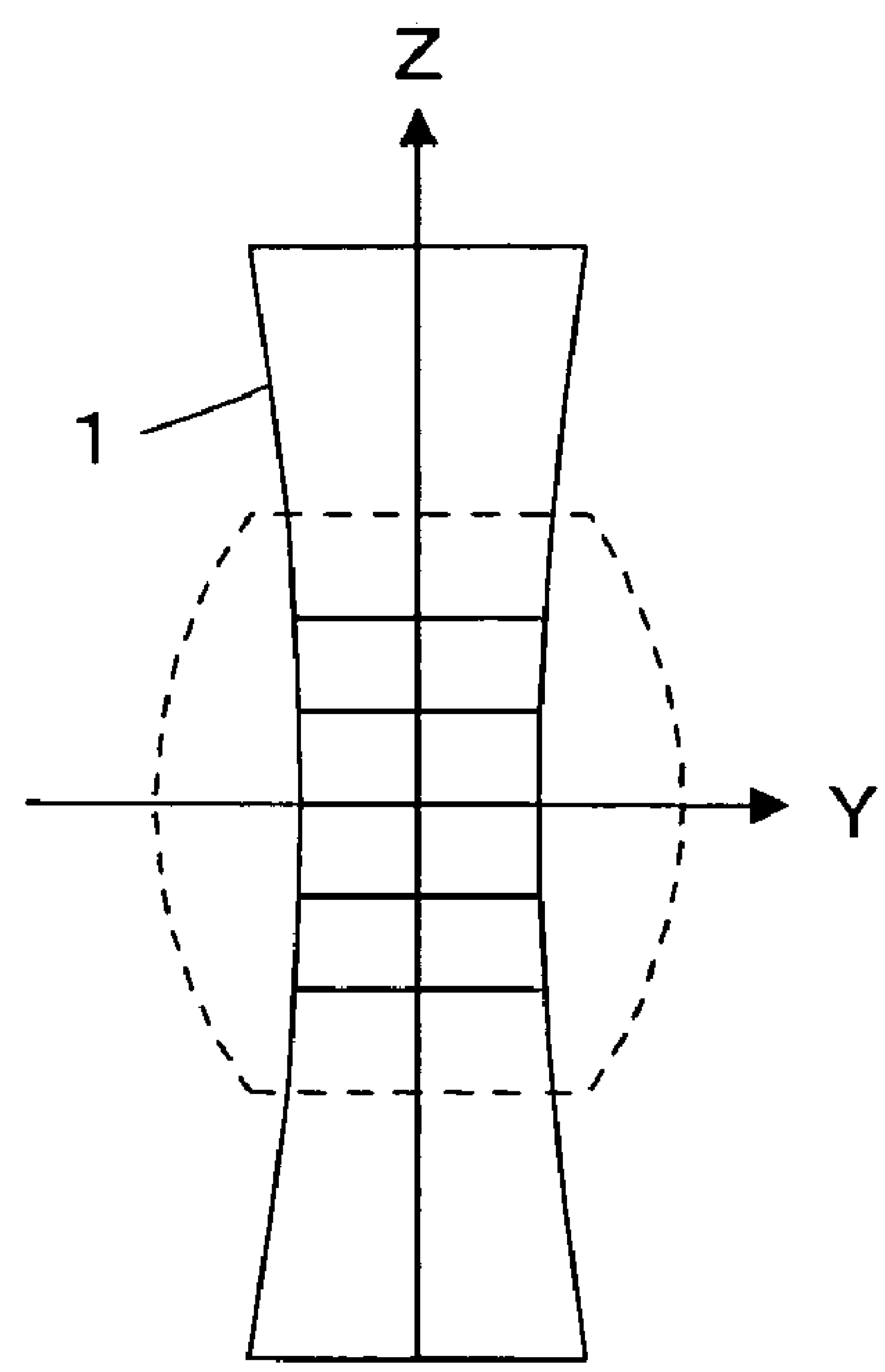


FIG.5b

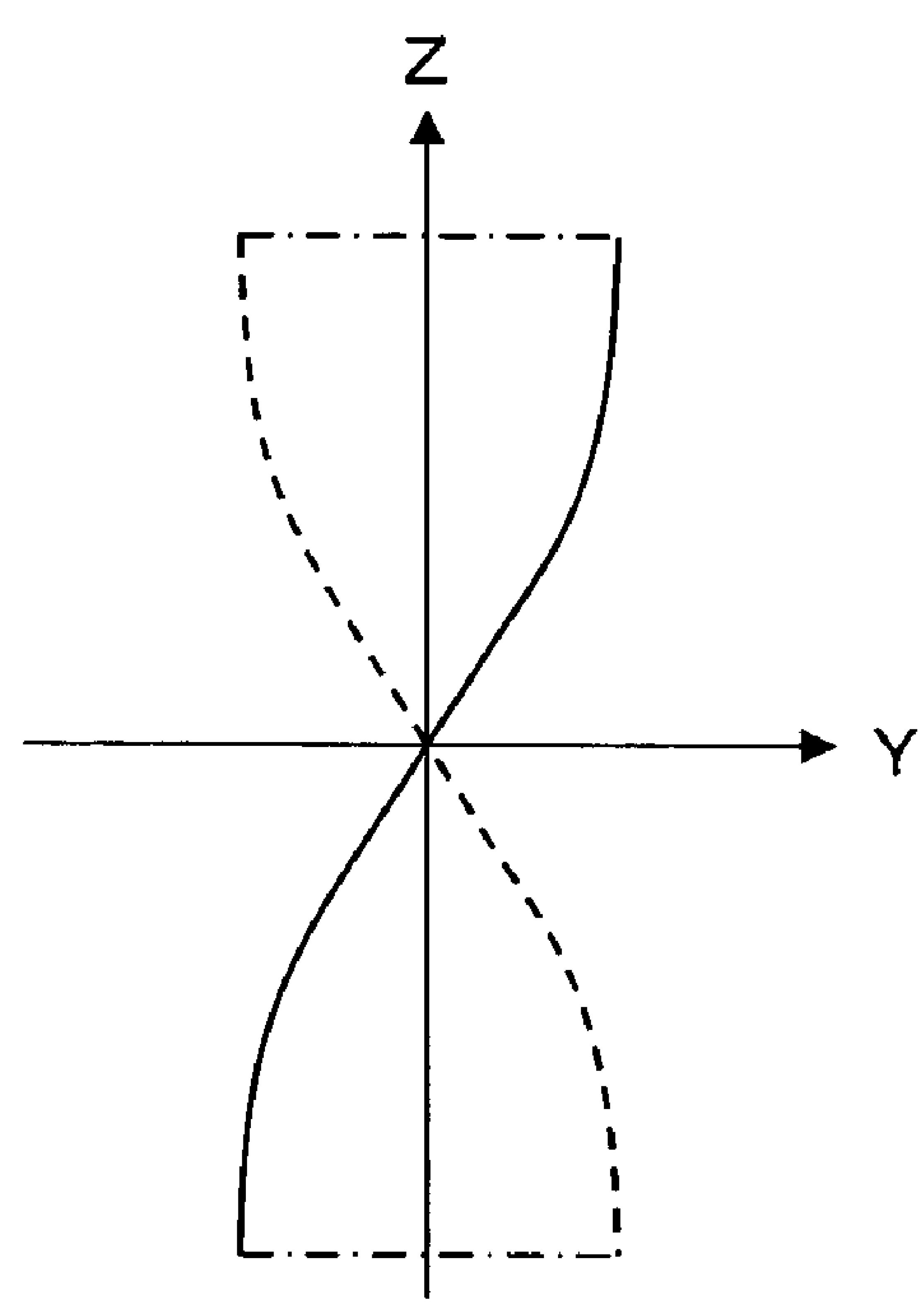


FIG.6

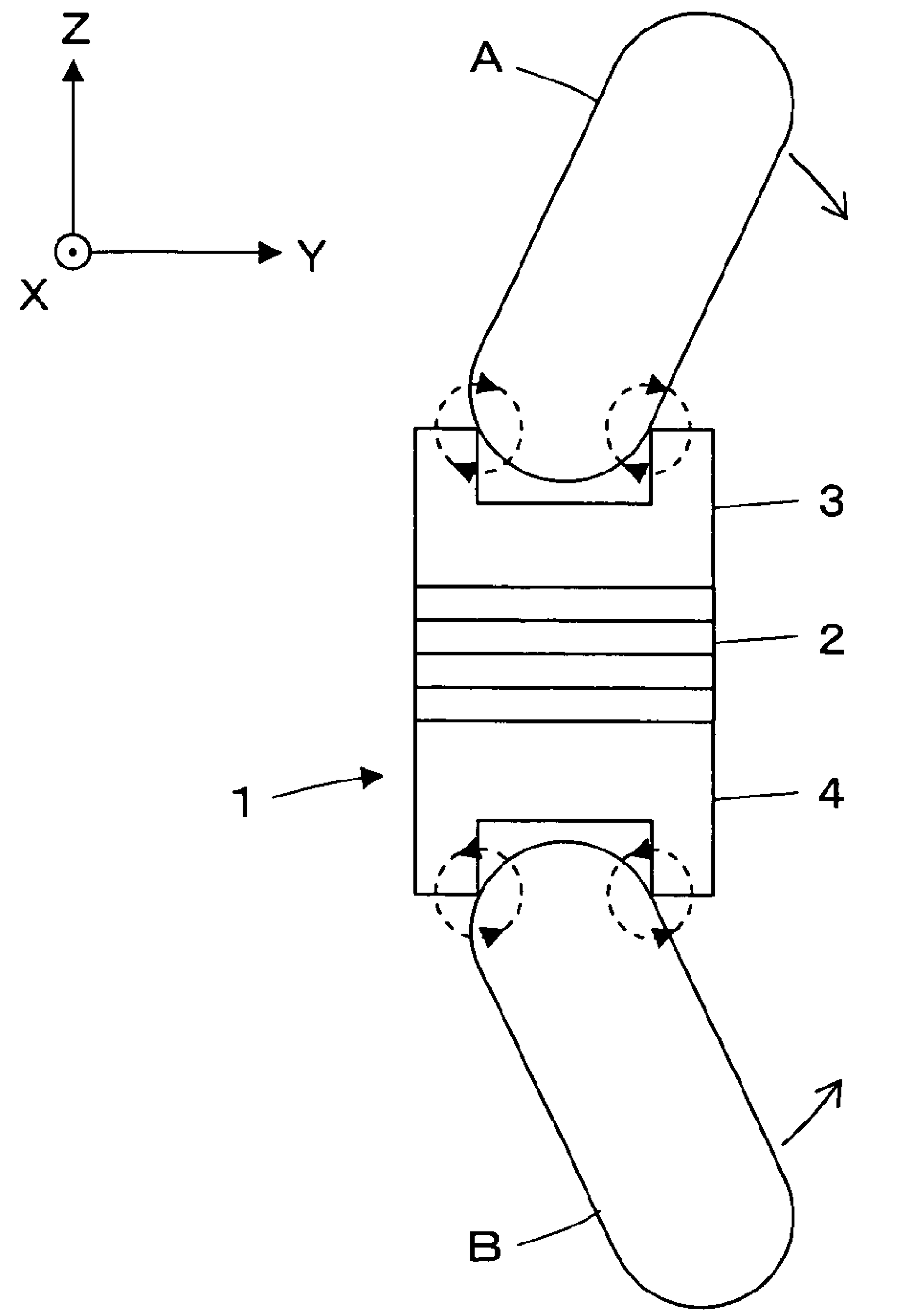


FIG.7

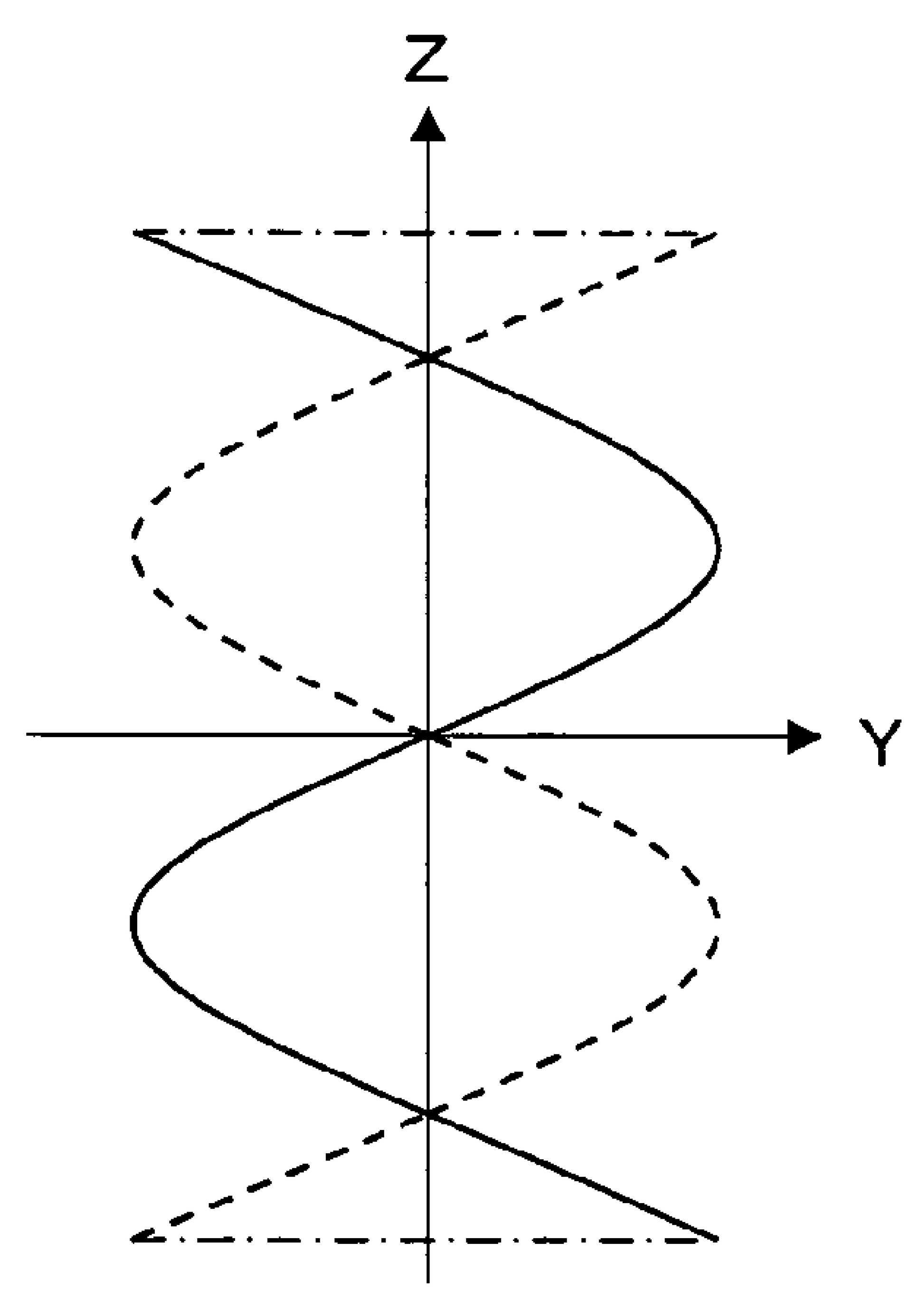


FIG.8

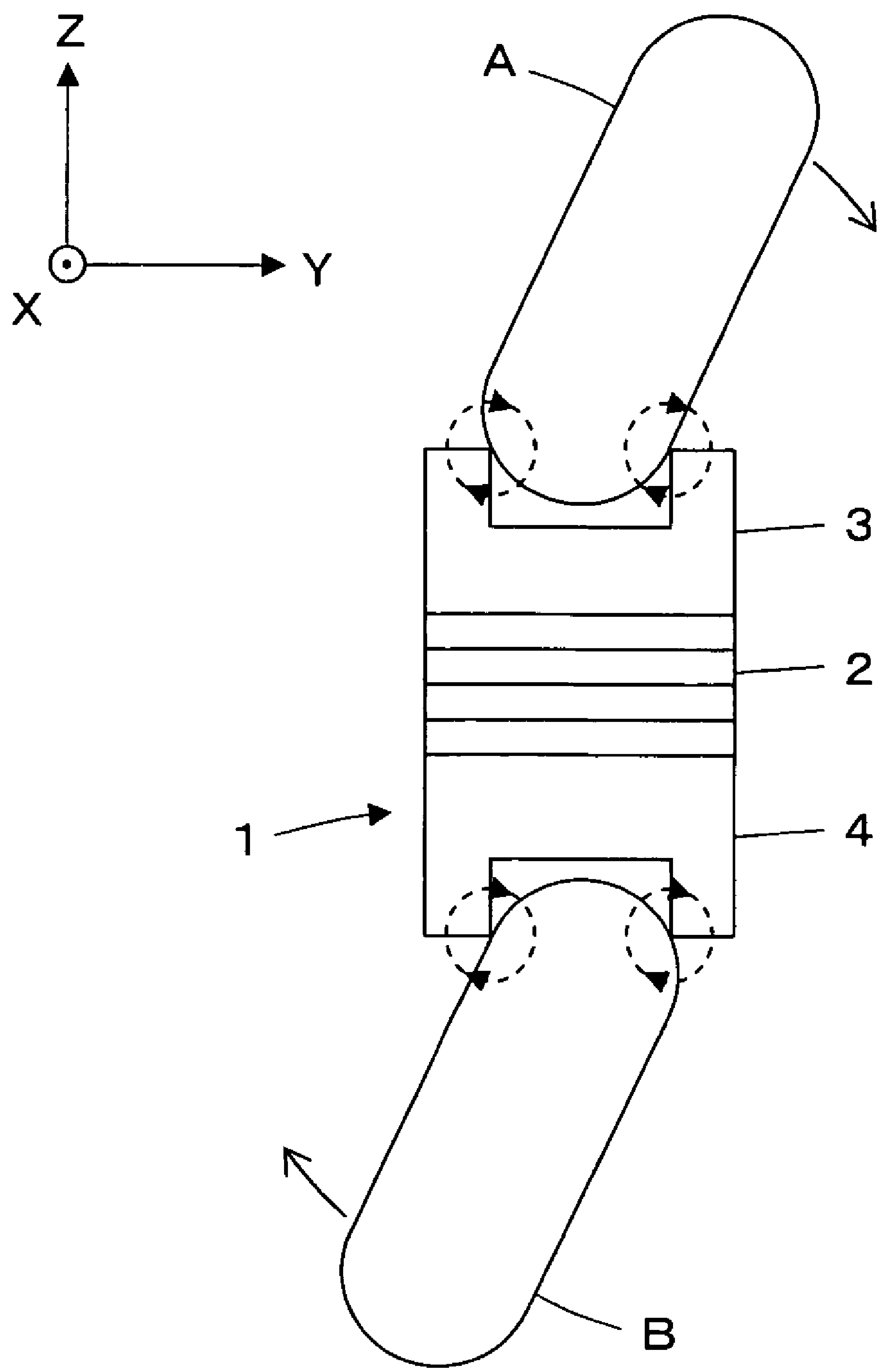


FIG.9

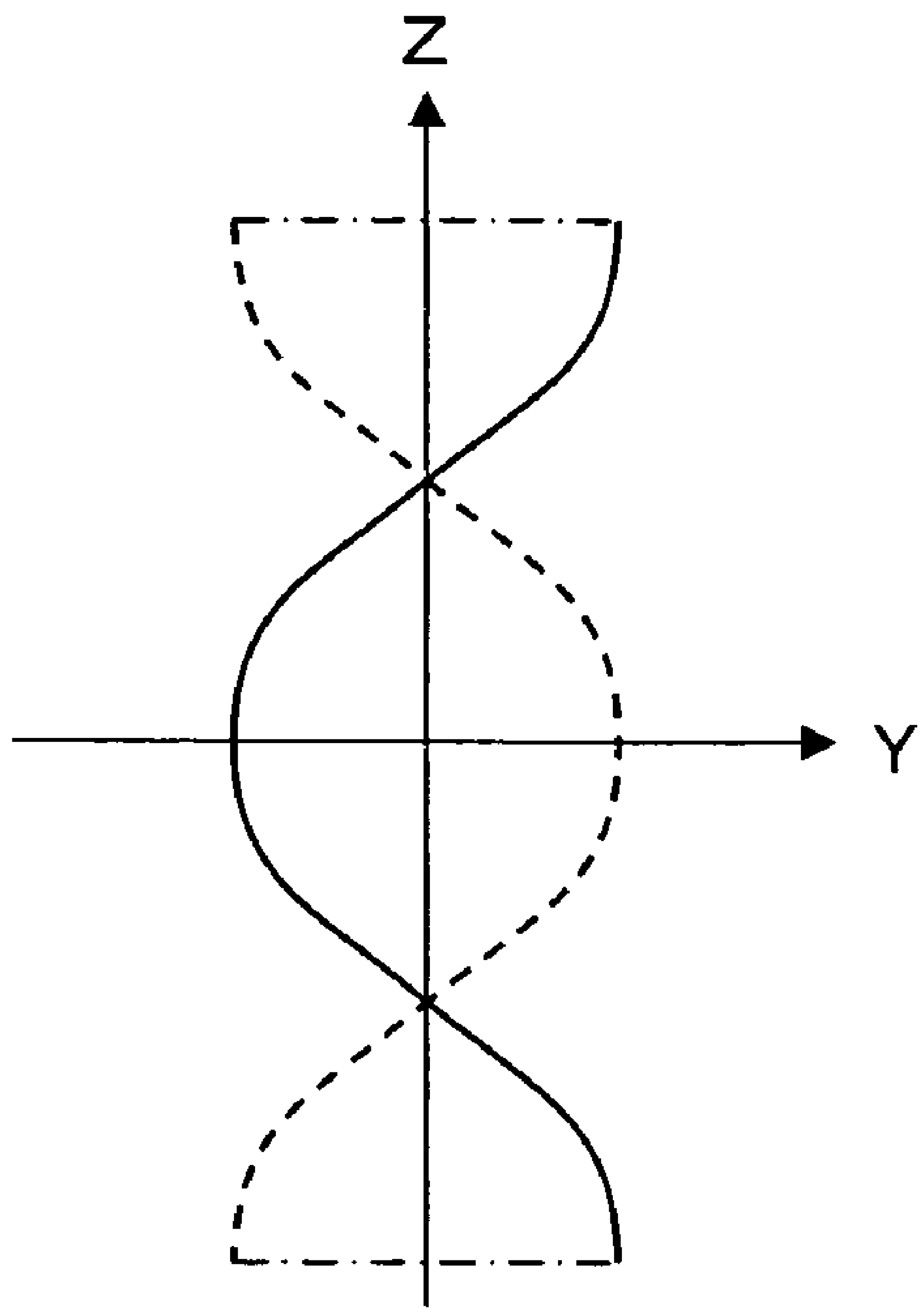


FIG.10

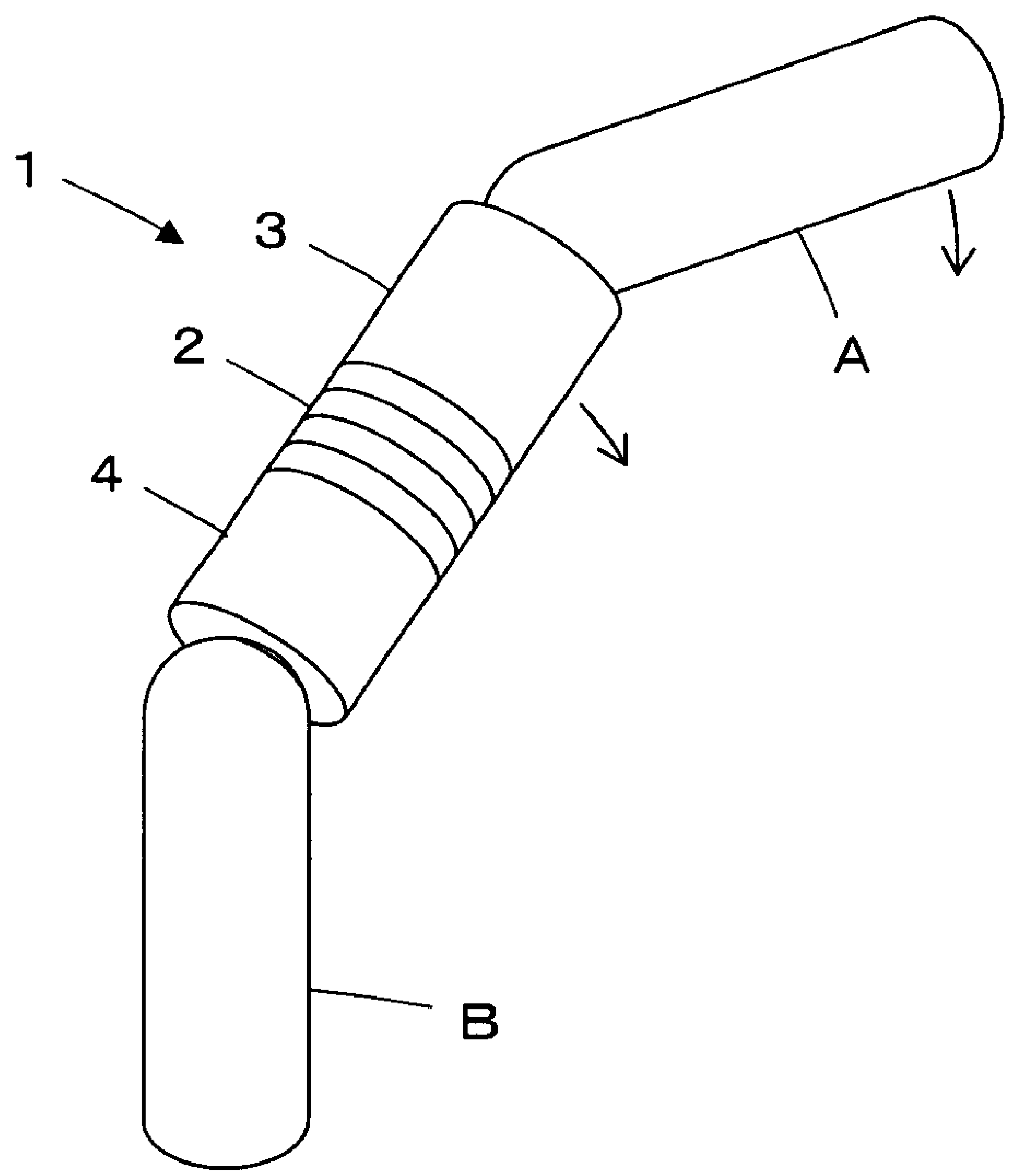


FIG.11

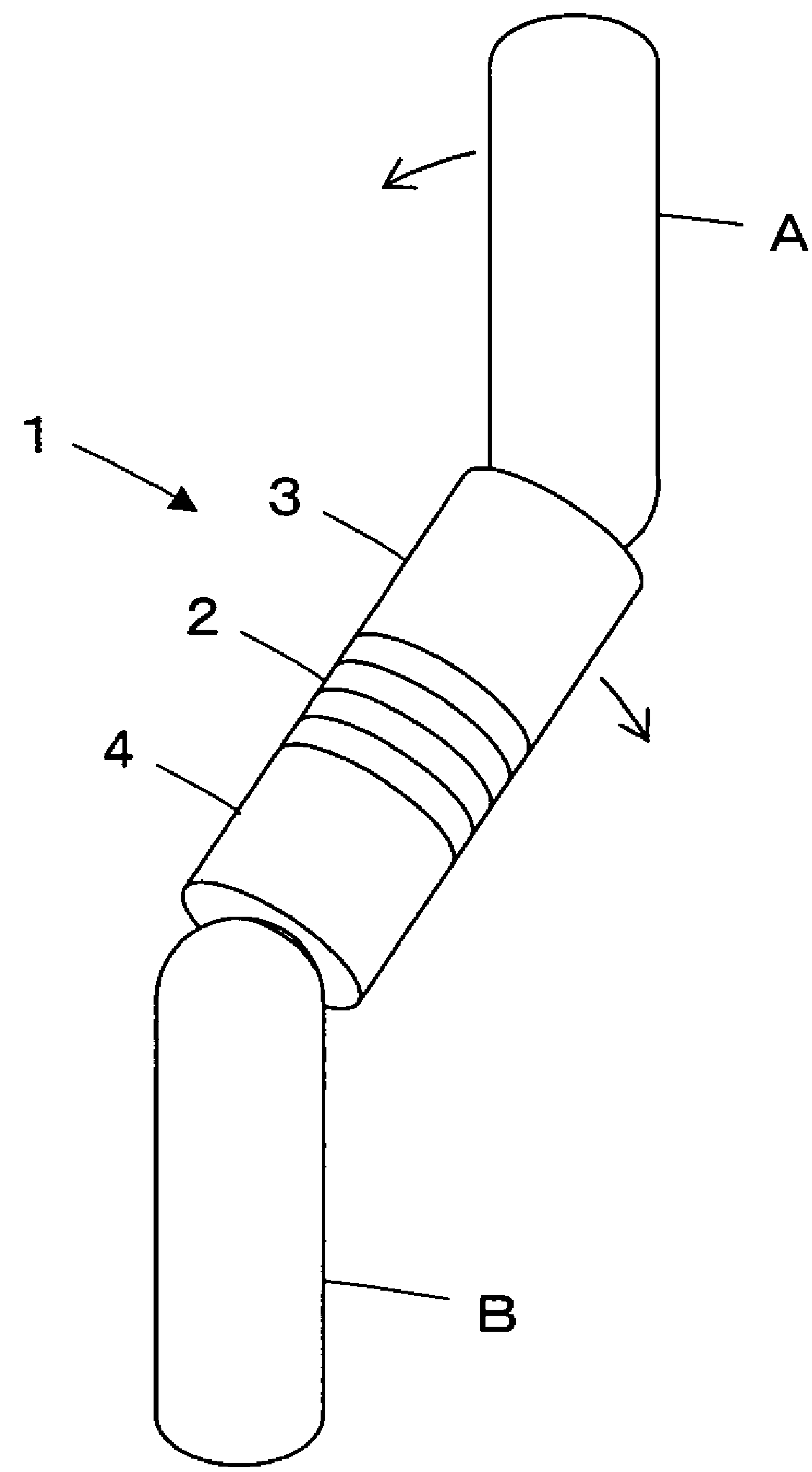


FIG.12

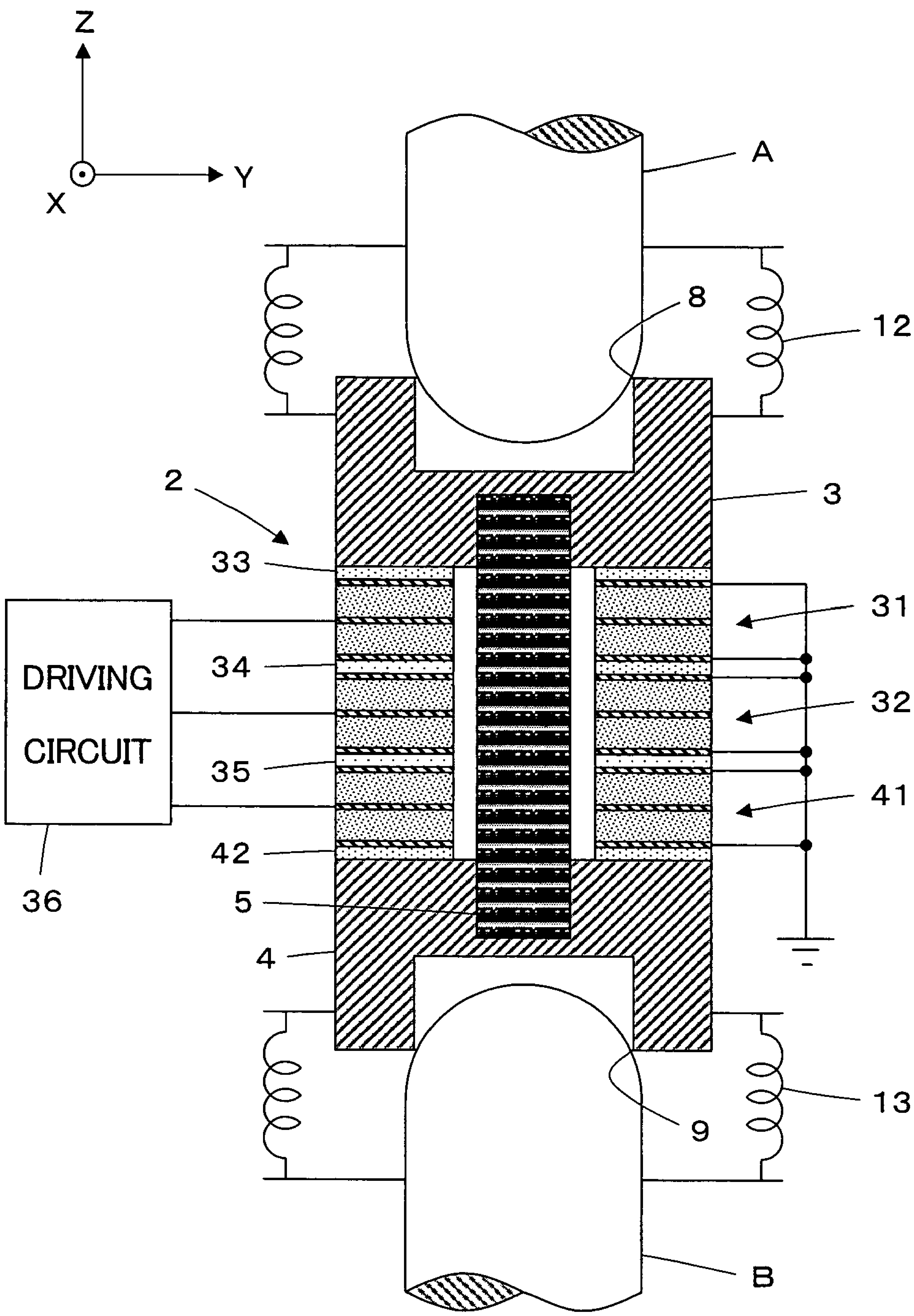


FIG.13

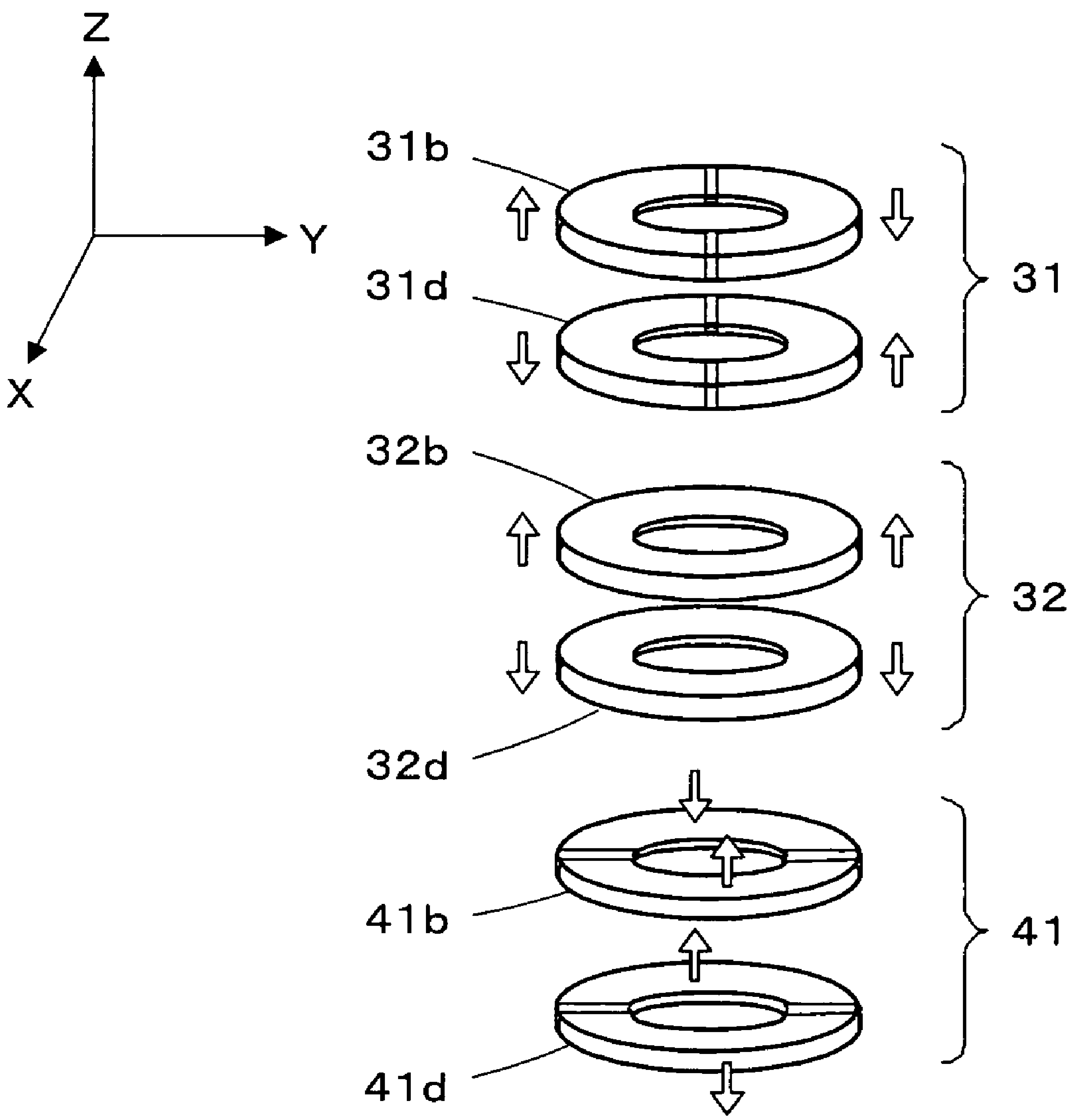


FIG.14

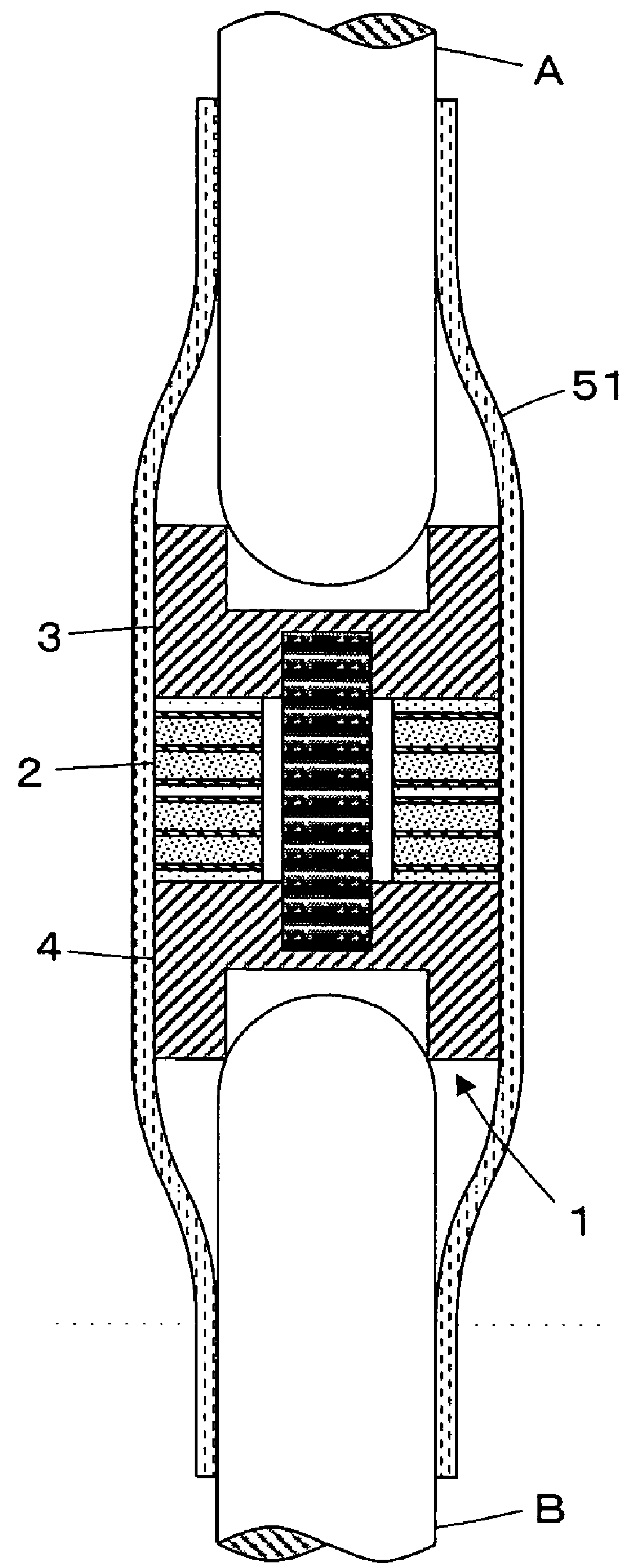


FIG.15

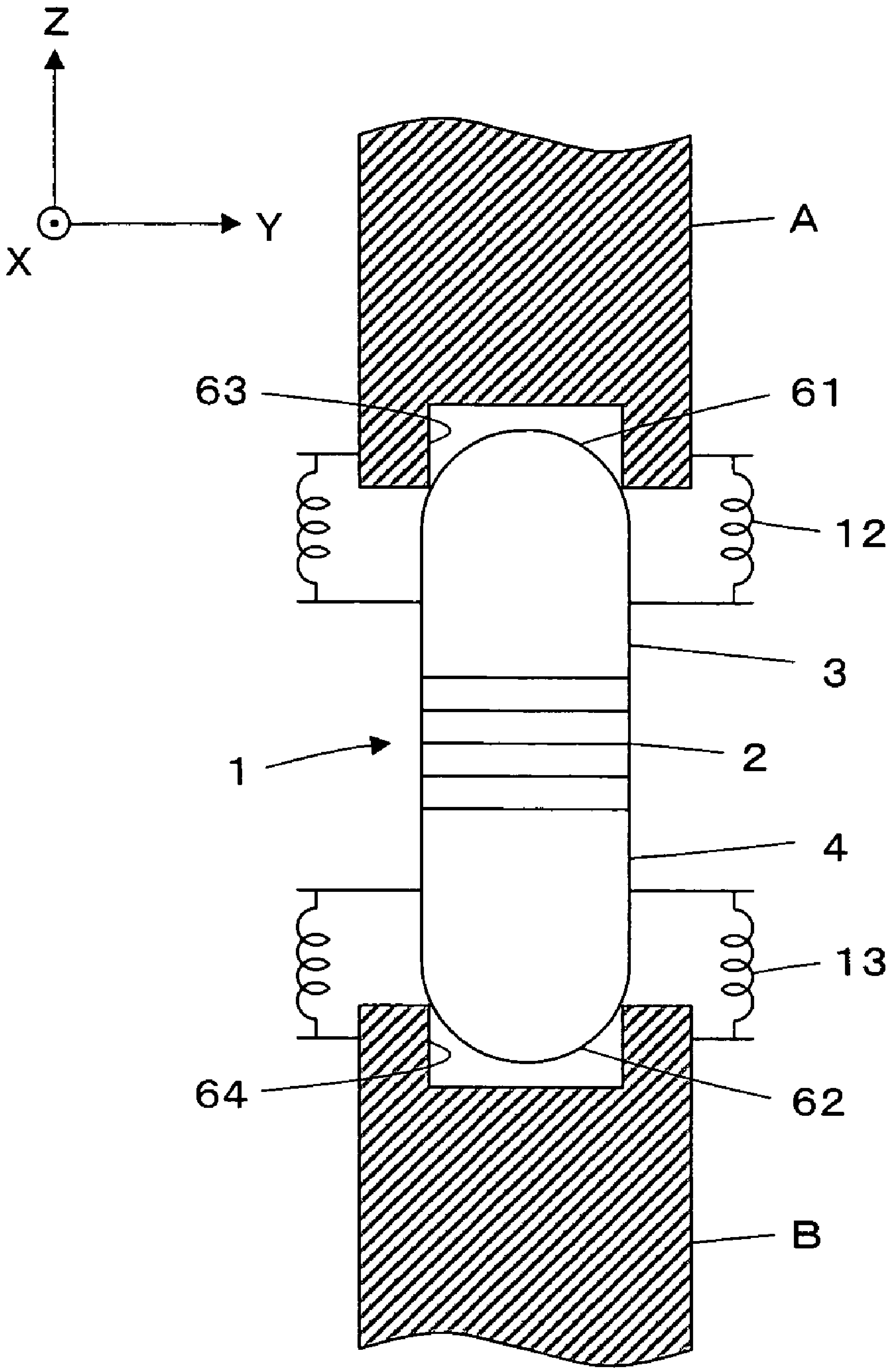


FIG.16

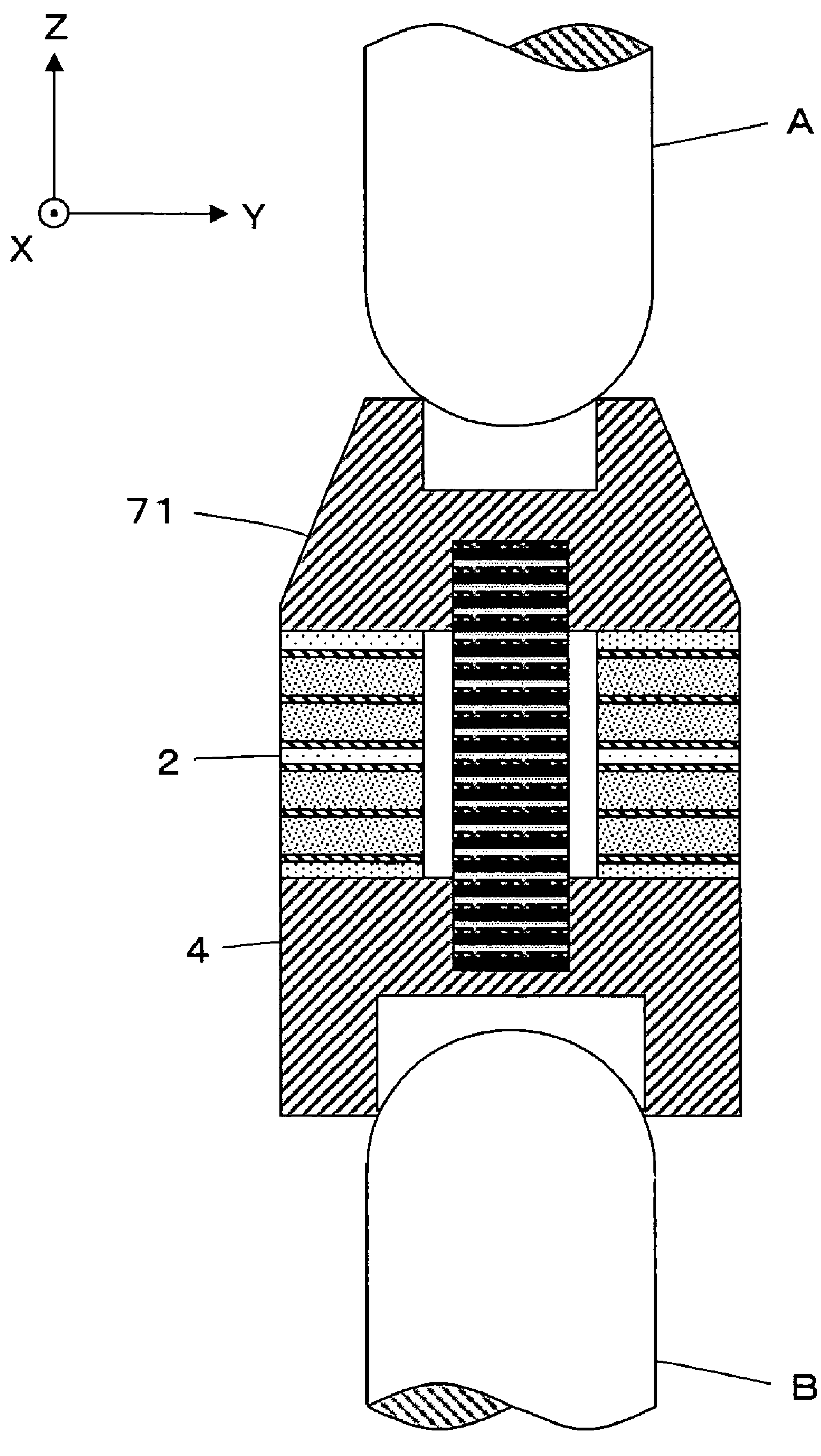


FIG.17

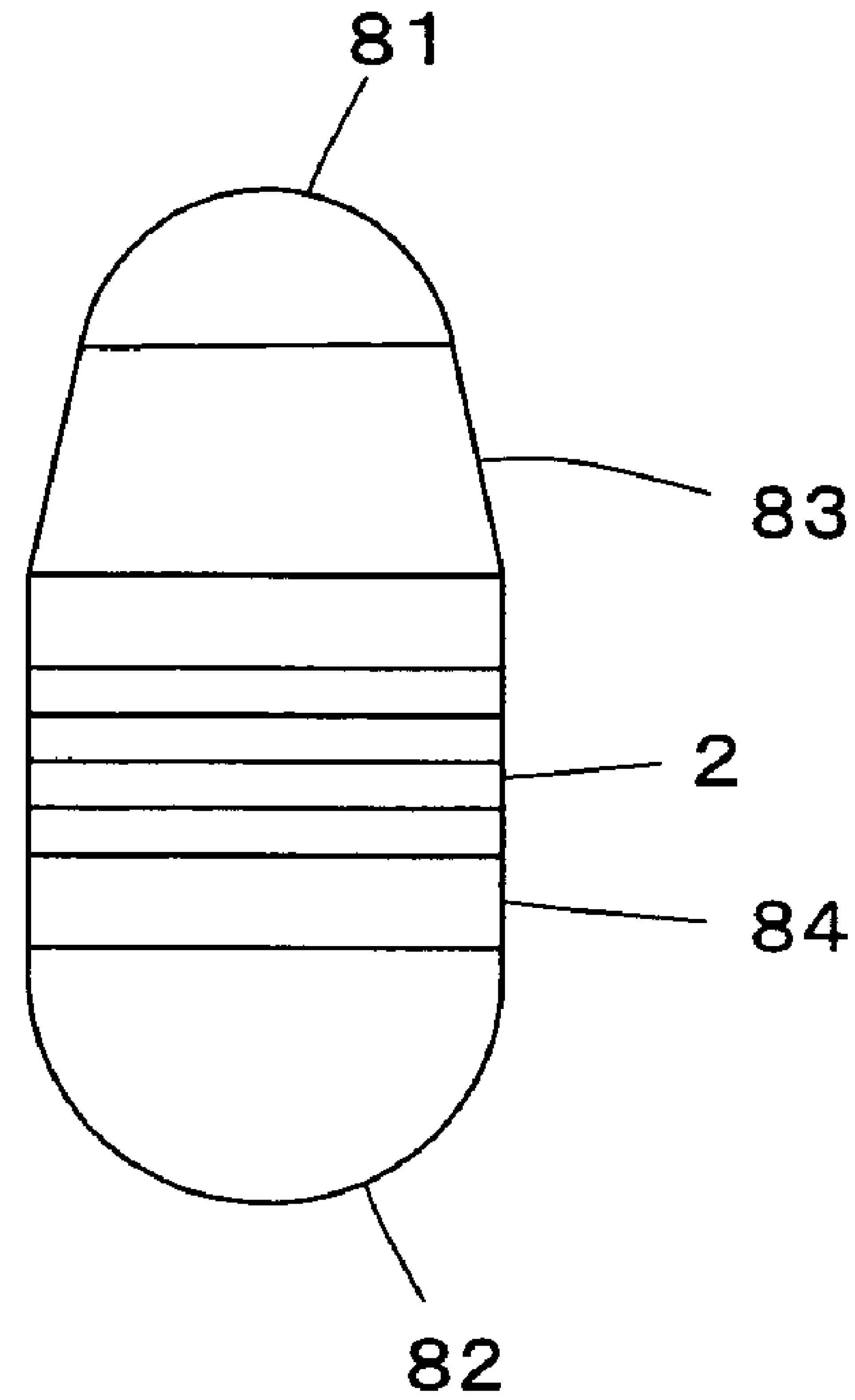
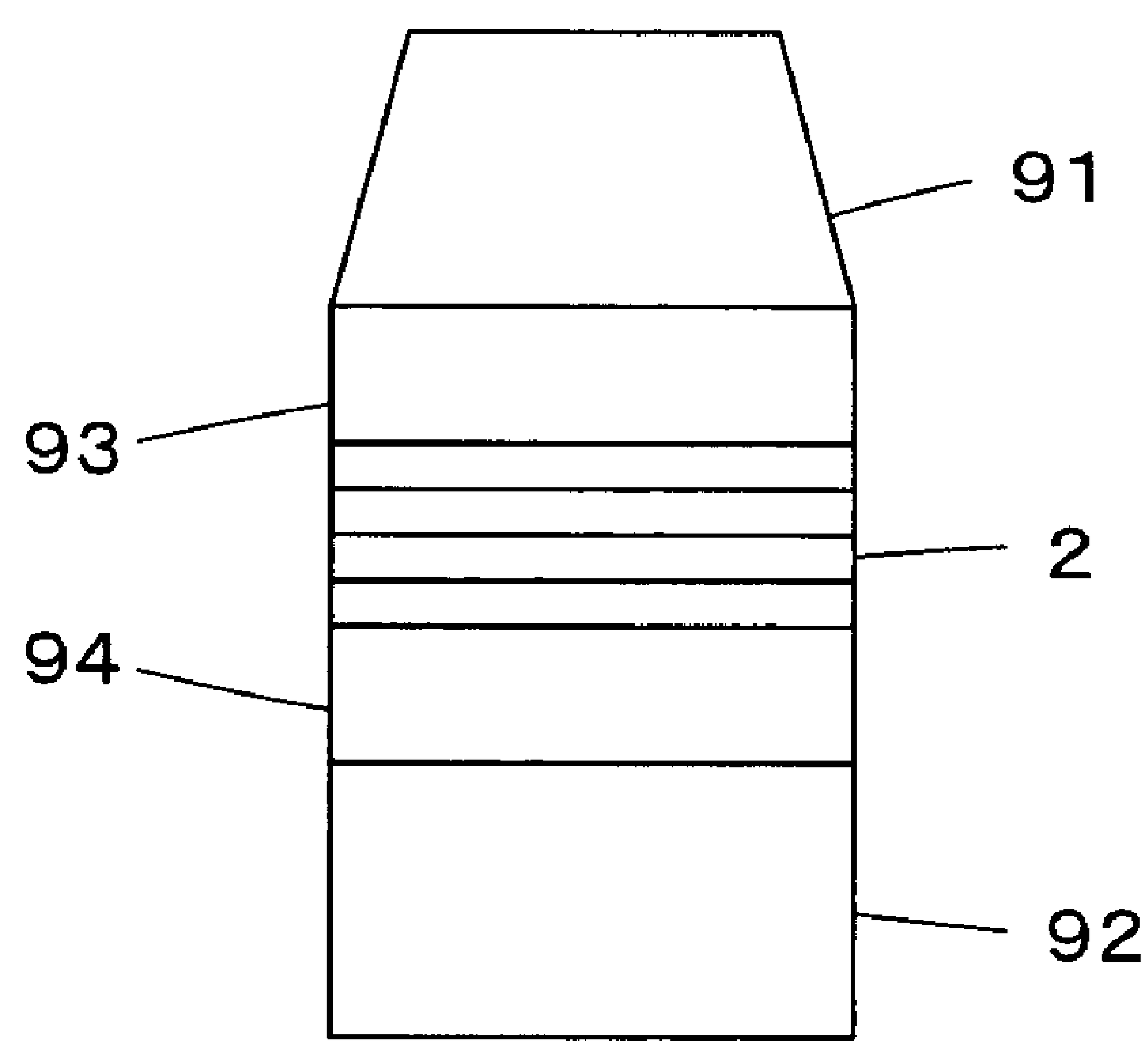


FIG.18



VIBRATION ACTUATOR

FIELD OF THE INVENTION

The present invention relates to a vibration actuator, and more specifically, to a vibration actuator in which a stator is caused to vibrate by a vibration means, thereby rotating a rotor in contact with the stator.

BACKGROUND OF THE INVENTION

For example, Patent Document 1 discloses a vibration actuator employing ultrasonic vibration to rotate a rotor. The vibration actuator has a composite vibrator as a vibration means, the vibrator including a plurality of piezoelectric element plates overlapping each other. A stator is arranged on one end portion of the composite vibrator, and a single rotor is supported by the stator so as to contact with the stator. By applying driving voltages to the plurality of piezoelectric element plates of the composite vibrator, a plurality of vibrations in different directions are generated and combined with each other to form a composite vibration. Then, the composite vibration causes the stator to vibrate, thereby rotating the rotor.

Patent Document 1: JP 11-220892 A

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

However, in the vibration actuator of Patent Document 1, a single composite vibrator rotates a single rotor. Therefore, when it is intended to rotate a plurality of rotors, respectively, it is necessary to provide a plurality of dedicated composite vibrators corresponding to the rotors, and to control driving of the plurality of composite vibrators independently of each other, thereby making the vibration actuator complicated.

The present invention has been made to solve the above-mentioned problems. It is an object of the present invention to provide a vibration actuator in which a plurality of rotors can be driven by a single vibration means.

Means for Solving the Problems

A vibration actuator according to the present invention includes: two stators; two rotors arranged so as to be in contact with the two stators, respectively; a single vibration means arranged between the two stators for generating a composite vibration combining a plurality of vibrations in different directions to vibrate the two stators, thereby rotating the two rotors at the same time.

EFFECT OF THE INVENTION

According to the present invention, it is possible to obtain a vibration actuator capable of driving a plurality of rotors by a single vibration means.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a sectional view showing a vibration actuator according to a first embodiment of the present invention.

FIG. **2** is a partial sectional view showing a structure of a composite vibrator used in the first embodiment.

FIG. **3** is a perspective view showing a polarization direction of two pairs of piezoelectric element plates of the composite vibrator used in the first embodiment.

FIG. **4***a* is a view showing a state where the actuator main body vibrates in a primary mode of a flexural vibration in a Y-axis direction.

FIG. **4***b* is a view showing displacement in the Y-axis direction of each portion of the actuator main body shown in FIG. **4***a*.

FIG. **5***a* is a view showing a state where the actuator main body vibrates in a primary mode of a longitudinal vibration in a Z-axis direction.

FIG. **5***b* is a view showing displacement in the Z-axis direction of each portion of the actuator main body shown in FIG. **5***a* with the displacement in the Z-axis direction converted into that in the Y-axis direction.

FIG. **6** is a view showing a state where two rotors in the first embodiment are rotated in directions opposite to each other.

FIG. **7** is a view showing displacement in the Y-axis direction of each portion of the actuator main body vibrating in a secondary mode of a flexural vibration in the Y-axis direction.

FIG. **8** is a view showing a state where the two rotors in the first embodiment are rotated in the same direction.

FIG. **9** is a view showing displacement in the Z-axis direction of each portion of the actuator main body vibrating in a secondary mode of a longitudinal vibration in the Z-axis direction with the displacement in the Z-axis direction converted into that in the Y-axis direction.

FIG. **10** is a view showing a state where the actuator main body and one rotor rotate in the same direction while the other rotor is fixed to a stationary object.

FIG. **11** is a view showing a state where the actuator main body and one rotor rotate in the opposite directions with respect to each other while the other rotor is fixed to a stationary object.

FIG. **12** is a sectional view showing a vibration actuator according to a second embodiment of the present invention.

FIG. **13** is a perspective view showing a polarization direction of three pairs of piezoelectric element plates of the composite vibrator used in the second embodiment.

FIG. **14** is a sectional view showing a vibration actuator according to a third embodiment of the present invention.

FIG. **15** is a sectional view showing a vibration actuator according to a fourth embodiment of the present invention.

FIG. **16** is a sectional view showing a vibration actuator according to a fifth embodiment of the present invention.

FIG. **17** is a side view showing an actuator main body in a modified example of the fifth embodiment of the present invention.

FIG. **18** is a side view showing an actuator main body in another modified example of the fifth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Hereinafter, embodiments of the present invention will be described with reference to the drawings.

First Embodiment

FIG. **1** shows a vibration actuator according to a first embodiment of the present invention. The vibration actuator is an ultrasonic actuator in which a rotor is rotated by utilizing ultrasonic vibration. The vibration actuator includes an actuator main body **1** and two rotors A and B rotated by the actuator main body **1**. The actuator main body **1** has a single cylindrical composite vibrator **2**, and a first stator **3** and a second stator **4** arranged on both end portions of the composite vibrator **2**, respectively. The first stator **3** and the second stator **4** sandwich the composite vibrator **2** therebetween and are connected to each other through a connection bolt **5** allowed to pass through the composite vibrator **2**, thereby constituting the actuator main body **1** having a substantially column-like outer configuration. Here, for convenience of description, it is assumed that a central axis of the actuator main body **1** extending from the second stator **4** to the first stator **3** is defined as a Z axis, an X axis extends perpendicularly to the Z axis, and a Y axis extends perpendicularly to both the Z axis and the X axis.

The composite vibrator **2** has a plate-like first piezoelectric element portion **31** and a plate-like second piezoelectric element portion **32** which are positioned on XY planes and are stacked on each other. The piezoelectric element portions **31** and **32** are arranged so as to be electrically insulated from the first stator **3** and the second stator **4**, respectively, and from each other through intermediation of insulating sheets **33** to **35**. Further, the vibration actuator has a driving circuit **36** which applies driving voltages to the first piezoelectric element portion **31** and the second piezoelectric element portion **32** to thereby drive them.

The first stator **3** and the second stator **4** are provided with recesses **6** and **7**, respectively, formed on the opposite sides to surfaces thereof in contact with the composite vibrator **2**. Opening end peripheral portions of the recesses **6** and **7** are formed with annular corner portions **8** and **9**, respectively, positioned on XY planes. Here, the first rotor A has a semispherical convex portion **10** opposed to the recess **6** of the first stator **3** and having a diameter larger than an inner diameter of the recess **6**. The convex portion **10** abuts onto the corner portion **8** of the first stator **3** to be rotatably supported. Similarly, the second rotor B has a semispherical convex portion **11** opposed to the recess **7** of the second stator **4** and having a diameter larger than an inner diameter of the recess **7**. The convex portion **11** abuts onto the corner portion **9** of the second stator **4** to be rotatably supported. Further, the rotors A and B are in contact with and pressurised against the corresponding stators **3** and **4** by springs **12** and **13**, respectively.

As shown in FIG. **2**, the first piezoelectric element portion **31** of the composite vibrator **2** has a structure in which an electrode plate **31***a*, a piezoelectric element plate **31***b*, an electrode plate **31***c*, a piezoelectric element plate **31***d*, and an electrode plate **31***e* each having a disc-like shape, are overlapped each other in the stated order. Similarly, the second piezoelectric element portion **32** has a structure in which an electrode plate **32***a*, a piezoelectric element plate **32***b*, an electrode plate **32***c*, a piezoelectric element plate **32***d*, and an electrode plate **32***e* each having a disc-like shape, are overlapped each other in the stated order.

The electrode plate **31***a* and the electrode plate **31***e* which are arranged on both surface sides of the first piezoelectric element portion **31**, and the electrode plate **32***a* and the electrode plate **32***e* which are arranged on both surface sides of the second piezoelectric element portion **32** are electrically grounded, respectively. Further, a terminal led out from the electrode plate **31***c* arranged between the pair of piezoelectric element plates **31***b* and **31***d* of the first piezoelectric element portion **31** is connected to the driving circuit **36**, and a terminal led out from the electrode plate **32***c* arranged between the pair of piezoelectric element plates **32***b* and **32***d* of the second piezoelectric element portion **32** is also connected to the driving circuit **36**.

As shown in FIG. **3**, each of piezoelectric element plates **31***b* and **31***d* of the first piezoelectric element portion **31** is divided into two portions in the Y-axis direction and is polarized so that the two portions thereof have opposite polarities to exhibit opposite deformation behaviors to each other, that is, expansion and contraction in the Z-axis direction (thickness direction). The piezoelectric element plate **31***b* and the piezoelectric element plate **31***d* are arranged in reverse orientations to each other.

Each of piezoelectric element plates **32***b* and **32***d* of the second piezoelectric element portion **32** is not divided into two portions and is polarized such that each plate **32***b* and **32***d* as a whole exhibits a deformation behavior, that is, expansion or contraction in the Z-axis direction (thickness direction). The piezoelectric element plate **32***b* and the piezoelectric element plate **32***d* are arranged in reverse orientations to each other.

Next, an operation of the vibration actuator according to the first embodiment of the present invention will be described. When an alternating current voltage is applied to the electrode plate **31***c* of the first piezoelectric element portion **31** by the driving circuit **36** to generate in the first piezoelectric element portion **31** the flexural vibration of the primary mode in the Y-axis direction, the two portions mutually divided of each piezoelectric element plate **31***b* and **31***d* of the first piezoelectric element portion **31** alternately repeat expansion and contraction in the Z-axis direction, therefore the actuator main body **1** vibrates as shown in FIG. **4***a*. Here, displacement in the Y-axis direction of each portion of the actuator main body **1** of FIG. **4***a* is shown in FIG. **4***b*. With reference to FIG. **4***b*, it is understood that both end portions of the actuator main body **1**, that is, the corner portion **8** of the first stator **3** and the corner portion **9** of the second stator **4** vibrate in the same phase.

Further, when an alternating current voltage is applied to the electrode plate **32***c* of the second piezoelectric element portion **32** by the driving circuit **36** to generate in the second piezoelectric element portion **32** the longitudinal vibration of the primary mode in the Z-axis direction, both of piezoelectric element plates **32***b* and **32***d* of the second piezoelectric element portion **32** alternately repeat expansion and contraction in the Z-axis direction, therefore the actuator main body **1** vibrates as shown in FIG. **5***a*. Here, displacement in the Z-axis direction of each portion of the actuator main body **1** of FIG. **5***a* is shown in FIG. **5***b* with the displacement in the Z-axis direction converted into that in the Y-axis direction. With reference to FIG. **5***b*, it is understood that both end portions of the actuator main body **1**, that is, the corner portion **8** of the first stator **3** and the corner portion **9** of the second stator **4** vibrate in the opposite phases with respect to each other.

Now, by applying the alternating current voltages having phases shifted by 90 degrees with respect to each other to the electrode plate **31***c* of the first piezoelectric element portion **31** and the electrode plate **32***c* of the second piezoelectric element portion **32**, a composite vibration combining the flexural vibration of the primary mode in the Y-axis direction and the longitudinal vibration of the primary mode in the Z-axis direction is generated by the composite vibrator **2**. In this case, the corner portion **8** of the first stator **3** and the corner portion **9** of the second stator **4** are displaced in the same phase in the Y-axis direction due to the flexural vibration of the primary mode in the Y-axis direction, and are displaced in opposite phases with respect to each other in the Z-axis direction due to the longitudinal vibration of the primary mode in the Z-axis direction. Thus, as shown in FIG. **6**, in the corner portion **8** of the first stator **3** and the corner portion **9** of the second stator **4**, elliptical movements in opposite directions with respect to each other are caused in a YZ plane. Accordingly, the first rotor A abutting onto and pressurized against the corner portion **8** of the first stator **3** and the second rotor B abutting onto and pressurized against the corner portion **9** of the second stator **4** are rotated in the opposite directions with respect to each other at the same time about the X axis.

Further, FIG. **7** shows the displacement in the Y-axis direction of each portion of the actuator main body **1** in a case where the flexural vibration of the secondary mode in the Y-axis direction is caused in the first piezoelectric element portion **31**. With reference to FIG. **7**, it is understood that the both end portions of the actuator main body **1**, that is, the corner portion **8** of the first stator **3** and the corner portion **9** of the second stator **4** vibrate in the opposite phases with respect to each other.

Now, by applying the alternating current voltages having phases shifted by 90 degrees with respect to each other to the electrode plate **31***c* of the first piezoelectric element portion **31** and the electrode plate **32***c* of the second piezoelectric element portion **32**, a composite vibration combining the flexural vibration of the secondary mode in the Y-axis direction and the longitudinal vibration of the primary mode in the Z-axis direction is generated by the composite vibrator **2**. In this case, the corner portion **8** of the first stator **3** and the corner portion **9** of the second stator **4** are displaced in the opposite phases with respect to each other in the Y-axis direction due to the flexural vibration of the secondary mode in the Y-axis direction, and are displaced in opposite phases with respect to each other in the Z-axis direction due to the longitudinal vibration of the primary mode in the Z-axis direction. Thus, as shown in FIG. **8**, in the corner portion **8** of the first stator **3** and the corner portion **9** of the second stator **4**, elliptical movements in the same direction are caused in the YZ plane. Accordingly, the first rotor A abutting onto and pressurized against the corner portion **8** of the first stator **3** and the second rotor B abutting onto and pressurized against the corner portion **9** of the second stator **4** are rotated in the same direction at the same time about the X axis.

As described above, by generating the composite vibration with the single composite vibrator **2** to thereby cause the elliptical movements in contact portions of the stators **3** and **4** abutting to the corresponding rotors A and B, respectively, the two rotors A and B can be rotated at the same time. Accordingly, by employing the vibration actuator of the present invention, a joint mechanism or the like having a plurality of joint portions to be rotated can be realized with a simple structure, thereby making it possible to achieve reduction in size and weight.

Further, by selecting a combination of a vibration mode of the longitudinal vibration in the Z-axis direction and a vibration mode of the flexural vibration in the Y-axis direction, the first rotor A and the second rotor B can be rotated in the same direction or in the opposite directions with respect to each other.

Since the vibration actuator is an ultrasonic actuator employing ultrasonic vibration, the vibration actuator has high torque performance and can be driven without using a gear.

Further, when the springs **12** and **13**, wirings for connecting the piezoelectric element portions **31** and **32** to the driving circuit **36**, and the like are accommodated in the inside of the actuator main body **1** and rotors A and B, the vibration actuator as a whole can be downsized.

Note that, FIG. **9** shows the displacement in the Z-axis direction of each portion of the actuator main body **1** in a case where the longitudinal vibration of the secondary mode in the Z-axis direction is caused in the second piezoelectric element portion **32** with the displacement in the Z-axis direction converted into that in the Y-axis direction. With reference to FIG. **9**, it is understood that the both end portions of the actuator main body **1**, that is, the corner portion **8** of the first stator **3** and the corner portion **9** of the second stator **4** vibrate in the same phase.

Accordingly, when the composite vibration combining the flexural vibration of the primary mode in the Y-axis direction and the longitudinal vibration of the secondary mode in the Z-axis direction is generated, similarly to the case where the composite vibration combining the flexural vibration of the secondary mode in the Y-axis direction and the longitudinal vibration of the primary mode in the Z-axis direction is generated, the two rotors A and B can be rotated in the same direction about the X axis.

Further, the vibration actuator can be used with the actuator main body **1** being fixed to a stationary object or with one of the first rotor A and the second rotor B being fixed to the stationary object.

For example, in a case where the second rotor B is fixed to the stationary object, when the composite vibration combining the longitudinal vibration of the primary mode in the Z-axis direction and the flexural vibration of the primary mode in the Y-axis direction is generated by the composite vibrator **2**, as shown in FIG. **10**, the actuator main body **1** relatively rotates with respect to the second rotor B, and the first rotor A rotates with respect to the actuator main body **1** in the same direction as the rotation direction of the actuator main body **1**.

Further, when, for example, the composite vibration combining the longitudinal vibration of the primary mode in the Z-axis direction and the flexural vibration of the secondary mode in the Y-axis direction is generated by the composite vibrator **2**, as shown in FIG. **11**, the actuator main body **1** relatively rotates with respect to the second rotor B, and the first rotor A rotates with respect to the actuator main body **1** in a direction opposite to the rotation direction of the actuator main body **1**.

Note that, instead of the first piezoelectric element portion **31** generating the flexural vibration in the Y-axis direction or of the second piezoelectric element portion **32** generating the longitudinal vibration in the Z-axis direction, a piezoelectric element portion generating a flexural vibration in the X-axis direction may be used. That is, by generating a composite vibration combining the flexural vibration in the X-axis direction and the longitudinal vibration in the Z-axis direction, or by generating a composite vibration combining the flexural vibration in the X-axis direction and the flexural vibration in the Y-axis direction, it is possible to rotate the two rotors A and B at the same time about the Y axis or the Z axis. Further, in both cases, by selecting a combination of the vibration modes of the two vibrations constituting the composite vibration, the two rotors A and B can be rotated in the same direction or in the opposite directions with respect to each other.

Second Embodiment

Next, with reference to FIG. **12**, a description will be made of a vibration actuator according to a second embodiment of the present invention. Compared to the first embodiment, in the second embodiment, the composite vibrator **2** has a third piezoelectric element portion **41** generating the flexural vibration in the X-axis direction in addition to the first piezoelectric element portion **31** generating the flexural vibration in the Y-axis direction and the second piezoelectric element portion **32** generating the longitudinal vibration in the Z-axis direction. The third piezoelectric element portion **41** has a pair of piezoelectric element plates **41***b* and **41***d* as shown in FIG. **13**. Each of piezoelectric element plates **41***b* and **41***d* is divided into two portions in the X-axis direction and is polarized so that the two portions thereof have opposite polarities to exhibit opposite deformation behaviors to each other, that is, expansion and contraction in the Z-axis direction (thickness direction). The piezoelectric element plate **41***b* and the piezoelectric element plate **41***d* are arranged in reverse orientations to each other.

Note that, the third piezoelectric element portion **41** has the same structure as that of the first piezoelectric element portion **31** or the second piezoelectric element portion **32** except for the pair of piezoelectric element plates **41***b* and **41***d*. The third piezoelectric element portion **41** is stacked together with the first piezoelectric element portion **31** and the second piezoelectric element portion **32**. A pair of electrode plates arranged on both surface sides of the third piezoelectric element portion **41** are electrically grounded, respectively, and an electrode plate arranged between the pair of piezoelectric element plates **41***b* and **41***d* is connected to the driving circuit **36**. Further, the three piezoelectric element portions **31**, **32**, and **41** are arranged so as to be electrically insulated from the two stators **3** and **4** and from each other through the intermediation of the insulating sheets **33** to **35** and an insulating sheet **42**.

When an alternating current voltage is applied to the electrode plate of the third piezoelectric element portion **41** by the driving circuit **36** to drive the third piezoelectric element portion **41**, the two portions mutually divided of each piezoelectric element plate **41***b* and **41***d* of the third piezoelectric element portion **41** alternately repeat expansion and contraction in the Z-axis direction. Therefore, the flexural vibration in the X-axis direction is generated in the first stator **3** and the second stator **4**.

By driving the composite vibrator **2** to generate a composite vibration combining at least two or all three vibrations of the flexural vibration in the Y-axis direction by the first piezoelectric element portion **31**, the longitudinal vibration in the Z-axis direction by the second piezoelectric element portion **32**, and the flexural vibration in the X-axis direction by the third piezoelectric element portion **41**, the elliptical movements are caused in the corner portion **8** of the first stator **3** and the corner portion **9** of the second stator **4**, respectively. Thus, the first rotor A and the second rotor B can be freely rotated on three-dimensions at the same time. Further, also in this case, the two rotors A and B can be rotated in the same direction or the opposite directions with respect to each other, by selecting the combination of the vibration mode.

Third Embodiment

Next, with reference to FIG. **14**, a description will be made of a vibration actuator according to a third embodiment of the present invention. Compared to the first embodiment, in the third embodiment, the two rotors A and B are caused to contact with and pressurized against the corresponding stators **3** and **4**, respectively, by using an elastic rubber cover **51**, instead of using the springs **12** and **13**. The rubber cover **51** has a cylindrical shape and covers an entire outer peripheral portion of the actuator main body **1**. Both end portions of the rubber cover **51** are fixed to outer peripheral portions of the first rotor A and the second rotor B, respectively, in a state where the rubber cover **51** is stretched in a central-axial direction. Due to a biasing force of the rubber cover **51**, the two rotors A and B are caused to contact with and pressurized against the corner portions **8** and **9** of the corresponding stators **3** and **4**, respectively. Accordingly, similarly to the first embodiment of the present invention, the two rotors A and B can be rotated by use of the single composite vibrator **2**.

Note that, also in the vibration actuator according to the second embodiment of the present invention, the rotors A and B can be caused to contact with and pressurized against the corresponding stators **3** and **4**, respectively, by using the rubber cover **51** instead of the springs **12** and **13**.

Fourth Embodiment

Next, with reference to FIG. **15**, a description will be made of a vibration actuator according to the fourth embodiment of the present invention. Compared to the first embodiment, in the fourth embodiment, relationships between the recesses of the stators **3** and **4** and the convex portions of the rotors A and B are reversed to each other. That is, the stators **3** and **4** have semispherical convex portions **61** and **62**, respectively, on the opposite sides to surfaces thereof in contact with the composite vibrator **2**. The rotors A and B are provided with recesses **63** and **64** formed in surfaces thereof opposed to the corresponding stators **3** and **4**, respectively. Opening end peripheral portions of the recesses **63** and **64** of the rotors A and B are provided with annular corner portions, respectively. The corner portions of the rotors A and B abut onto the convex portions **61** and **62** of the corresponding stators **3** and **4**, respectively, to be rotatably supported.

Note that, similarly to the first embodiment of the present invention, the rotors A and B are caused to contact with and pressurized against the corresponding stators **3** and **4** by the springs **12** and **13**, respectively.

Even with this structure, by generating a composite vibration with the composite vibrator **2** to thereby cause elliptical movements in contact portions of the stators **3** and **4** abutting to the corresponding rotors A and B, respectively, the two rotors A and B can be rotated. Further, by selecting a combination of vibration modes of two vibrations constituting the composite vibration, the two rotors A and B can be rotated in the same direction or in the opposite directions with respect to each other. As a result, the same effect as that of the first embodiment of the present invention can be obtained.

Note that, also in the vibration actuator according to the second and third embodiments of the present invention, the stators **3** and **4** may be provided with the convex portions and the rotors A and B may be provided with the recesses.

Fifth Embodiment

Next, with reference to FIG. **16**, a description will be made of a vibration actuator according to a fifth embodiment of the present invention. Compared to the first embodiment, in the fifth embodiment, a stator **71** formed so as to be gradually reduced in diameter toward a contact portion abutting to the rotor A is used as the first stator while the second stator **4** is used as it is. Therefore, at a time of driving of the composite vibrator **2**, the elliptical movement caused in the contact portion of the first stator **71** abutting to the rotor A has an amplitude larger than that of the elliptical movement caused in the contact portion of the second stator **4** abutting to the rotor B. Thus, a torque generated in the first rotor A becomes larger than a torque generated in the second rotor B. As described above, by forming the contact portions of the first stator **71** and the second stator **4** abutting to the corresponding rotors A and B, respectively, into different shapes with respect to each other, torques of different magnitudes can be generated in the two rotors A and B.

Note that, also in the second and third embodiments of the present invention, by forming the contact portions of the two stators abutting to the corresponding rotors A and B, into different shapes with respect to each other, the torques of different magnitudes can be generated in the two rotors A and B, respectively.

Further, in the fourth embodiment of the present invention, there may be used, for example, a pair of stators **83** and **84** having semispherical convex portions **81** and **82** which differ in radius from each other as shown in FIG. **17**, or a pair of stators **93** and **94** having a truncated cone-shaped convex portion **91** gradually reduced in diameter toward a tip thereof and a column-shaped convex portion **92**, respectively, as shown in FIG. **18**. In both cases, torques of different magnitudes can be generated in the two rotors A and B, respectively.

Note that, instead of stators, the contact portions of the two rotors abutting to the corresponding stators may be formed into different shapes or different sizes with respect to each other.

Further, in the above embodiments, the flexural vibration in the X-axis direction, the flexural vibration in the Y-axis direction, and the longitudinal vibration in the Z-axis direction are generated by different piezoelectric element portions, and the composite vibration is generated by combining the vibrations. However, one piezoelectric element portion may be divided into a plurality of portions, each of which is polarized, to separately control voltages applied to electrodes corresponding to the polarized portions. That is, the voltages in which alternating current voltages different from each other in phases and amplitudes or the like are mutually combined may be applied to the electrodes to generate a composite vibration by a single piezoelectric element portion.

Further, in the above embodiments, the elliptical movement is caused in the contact portion between the stator and the rotor. However, a circular movement may be caused in the contact portions by controlling amplitudes in respective axial directions thereof.

The invention claimed is:

1. A vibration actuator, comprising:

two stators;

two rotors arranged so as to be in contact with the two stators, respectively;

a single vibration means arranged between the two stators for generating a composite vibration combining a plurality of vibrations in different directions to vibrate the two stators, thereby rotating the two rotors at the same time;

wherein contact portions of the two stators abutting to the corresponding rotors are formed in sizes different from each other.

2. A vibration actuator according to claim **1**, further comprising a driving circuit for driving the vibration means,

the driving circuit selecting a combination of vibration modes of the plurality of vibrations constituting the composite vibration generated by the vibration means to thereby rotate the two rotors in the same direction with each other.

3. A vibration actuator according to claim **1**, further comprising a driving circuit for driving the vibration means,

the driving circuit selecting a combination of vibration modes of the plurality of vibrations constituting the composite vibration generated by the vibration means to thereby rotate the two rotors in opposite directions with respect to each other.

4. A vibration actuator according to claim **1**, wherein the vibration means comprises a composite vibrator including a plurality of piezoelectric element plates stacked on each other,

the two stators being arranged on both end portions in a stacking direction of the piezoelectric element plates, respectively.

5. A vibration actuator according to claim **4**, wherein the plurality of piezoelectric element plates correspond to the plurality of vibrations in different directions.

6. A vibration actuator according to claim **1**, wherein contact portions of the two stators abutting to the corresponding rotors are formed into shapes different from each other.

7. A vibration actuator according to claim **1**, wherein the contact portions of the two stators abutting to the corresponding rotors are formed to have spherical surfaces with radii different from each other.

8. A vibration actuator according to claim **1**, wherein the contact portions of the two stators abutting to the corresponding rotors are formed to have circumferential surfaces with radii different from each other.

9. A vibration actuator according to claim **1**, wherein the vibration means generates the composite vibration to cause elliptical movements in contact portions of the stators abutting to the corresponding rotors so that the two rotors are rotated at the same time.

10. A vibration actuator according to claim **1**, wherein the vibration means generates the composite vibration to cause circular movements in contact portions of the stators abutting to the corresponding rotors so that the two rotors are rotated at the same time.

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